Two samples collected at 5.15 on March 24 showed an average of 6 per cent moisture, the result of two days' drying with light to medium winds, clear weather and relative humidity generally below 50 per cent. By 8 a. m. March 25 the wind had shifted to the south and vapor pressure was rising, but due to a considerable rise in temperature during the day the relative humidity ranged between 52 per cent and 38 per cent. A light rain started just before 5 p. m., continuing at intervals during the night. A fall of 0.24 inch of rain was recorded by the gauge at the place of the tests. This was enough to wet the top leaves, but not enough to wet the litter throughout.

The first determinations made on March 26 showed a moisture content of 137 per cent of the oven-dry weight. During the day, which was cloudy with a temperature below 50 degrees and a humidity above 50 per cent, the litter dried down to about 25 per cent. During the night of March 26, the relative humidity ranged from 70 per cent to 90 per cent, and the litter absorbed moisture up to 54.5 per cent at 8 a. m., March 27. This day was moderately dry with fluctuating light winds, and relative humidity remaining above 40 per cent. The litter dried out to about 5 per cent by 4 p. m., when the falling temperature caused the relative humidity to advance sharply. Freezing temperature developed during the night. Five determinations made on March 28 at 3 p. m. agreed within 2 per cent and averaged 5.7 per cent moisture content. At this time relative humidity was 19 per cent and vapor pressure 0.069 inch.

The period of these tests was not exceedingly dry except at its close. High night humidities, the absence of brisk winds, and comparatively low temperature were all unfavorable to rapid drying. Still on four days out of five the top litter had dried to 7 per cent or lower, and even on March 26 fire would have burned between the hours of 3 and 4 p. m. This series of tests tends to verify that of the fall of 1925, the conclusion being that one day of sunshine with even medium winds and humidity at or below 50 per cent creates a fire hazard. Temperature is chiefly important because of its influence upon relative humidity.

SUMMARY

After the fall of the new litter a fire hazard can be created through the agency of sun, wind, and low relative humidity on south exposures in a single day following a heavy precipitation.

On north exposures during the fall season, due to the small angle of insolation and shade cast even by hardwood crowns, no material hazard can be created in one day.

Wind is necessary for rapid drying, especially on north exposures.

Leaves absorb more than their dry weight of water and absorb moisture from moist air without the agency of rain, dew, or frost. The moisture content of litter is thus affected by night humidities.

The period of active drying during the fall season o 1925 was limited to 6 or 7 hours during midday even on the more hazardous days. High relative humidity was common throughout all nights after the leaf crop came down.

Low moisture content can be estimated by a breaking test.

The conclusions from the fall season of 1925, as regards drying rate on south slopes, were generally verified in the spring season, although lower moisture percentages were found.

Conditions of wind, sunshine, and relative humidity favorable to forest fire are the regular aftermath of the passage of a storm, and can be forecast with more certainty than precipitation.

Unusual hazard is caused by continuation of high pressure over or west of the Appalachian region, or by the passing of a storm without precipitation in the region.

LIGHTNING STORMS AND FOREST FIRES IN THE STATE OF WASHINGTON

By GEORGE W. ALEXANDER

[Fire-Weather Warning Service, Seattle, Wash., March 4, 1927]

The lightning storm, usually called the thunderstorm, might appear to be a somewhat unimportant climatic factor in the Pacific Northwest to one basing an opinion on published compilations of thunderstorm frequency. Isoceraunics based on reports from Weather Bureau stations for the 20-year period 1904–1923 (*1*) indicate an annual frequency of 5 storms or less for the coastal regions of Washington and 10 or less for the rest of the State, except the extreme southeastern corner. For the period of record at the different stations, varying from 35 to 45 years, the annual averages of number of storms reported are: For Seattle, 5; for Walla Walla, 7; and for Spokane, 8. The reported frequency for the entire Pacific coast is similar, except that an annual average of 15 storms is ascribed to eastern Oregon, to Idaho, and to western Montana.

On the other hand, reports of the number of lightning-caused fires on the national forests and on State and privately owned timberlands in the coast States show that such storms are of extreme importance. For the season of 1926 the grand total of lightning fires was 3,520, or 36 per cent of all the fires reported in California, Oregon, Washington, Idaho, western Montana, and British Columbia. Of these, 2,468 were on the national forests (51 per cent of all fires on the forests). For the 1926 season in the State of Washington there were 192 lightning fires on the national forests and 126 on private and State lands, being 48 and 11 per cent, respectively, of the total number of fires; and the damage caused, especially in eastern Washington, was even greater, in proportion to the total damage from fires, than the numerical percentage would indicate. For the season of 1925 the lightning fires on the national forests numbered 253 (54 per cent of the total) and on other lands 155 (13 per cent); the records for preceding years show similar numbers and percentages.

These figures indicate, especially to one studying the effect of weather on fire hazard, that, far from being negligible or incidental, lightning must be considered as of major importance, particularly in the mountainous regions in which is located most of the national forest area, and that fire-weather warnings which do not localize to the greatest possible extent the imminence of lightning storms fail in a large measure to achieve their purpose.

Realizing the need for complete data on the occurrence of lightning storms for purposes of both record and research, the Forest Service in 1924 furnished their mountain lookouts with forms on which to record the date, hours of beginning and ending, direction of movement, amount of accompanying precipitation, and other pertinent data as to each storm passing within vision or hearing, with an accompanying report on all fires attributable to each storm. On many of the forests the number and location of lookouts makes it fairly certain that each storm, during the period the lookout stations were manned, has been reported. On other forests, where the general fire hazard is normally less and the number of lookouts is smaller and their season shorter, and on outside lands, where no such stations report, this is by no means the case, and it is fairly certain that unreported storms have occurred.

Reports from the national forests for 1924, 1925, and 1926 are now available, and, supplemented by those from cooperative observers and special fire-weather service observers of the Weather Bureau, and by reports of lightning-caused fires from the field personnel of the Washington Forest Fire Association, which covers western Washington outside the national forests, they have been made the basis of a survey of the frequency and geographical distribution of lightning over the State. With a view to improving the accuracy and localization of forecasts, the data have also been used in studying the meteorological conditions antecedent to and accompanying lightning storms.

Due regard must be given the quality of the reports on which such a study is based. They may be held to be entirely accurate as to dates and locations of storms reported, and fairly so as to the number of resultant fires. The precipitation is not for the most part measured instrumentally, and the amounts reported, as also the percentage of lightning flashes confined to the clouds, depend largely on the observer's judgment and point of view. Many of the reports show careful preparation; others do not. On the whole, they may be considered reliable as to dates, hours, and locations of storms and fires reported, but they can not be taken as excluding the possibility that other storms and fires occurred. They are most reliable and inclusive in late June, July, and August and least inclusive in May, early June, and September. The other months are not considered in this study, since the probability is small that many storms or important damage from them will occur in this region during the period of major cyclonic activity and comparatively low temperatures.

In 1924, from the beginning of reporting (various dates in July) to the closing of the lookout stations, lightning storms occurred on 21 days. There were 37 such days in 1925 and 29 in 1926. Reports of lightning fires indicate that there were probably storms on other days during these seasons, but the dates can not be fixed accurately. The numbers of storms reported vary with the location of the station and the length of the period reported on, from a minimum of 1 per season to a maximum of 14, with an average of about 8. Thus, based on the average number of storms reported per station rather than on the aggregate of days with storms, the frequency of storms for this region would be about that noted in the first paragraph.

The 87 known dates of storms noted above for the three seasons are the basis of this study. The location of each reported storm has been plotted on a map of the State, a separate map for each storm day. Pressure distribution, temperature, humidity, precipitation, and wind direction and velocity over the affected areas have been analyzed, to discover, if possible, the reasons for the known distribution of storms. For two reasons the synoptic charts for 8 p. m. (seventy-fifth meridian time) have been used in this study—first, because the abnormalities of pressure and temperature distribution most favorable to lightning storms are more notable on these than on the morning charts; second, fire-weather forecasts and warnings are distributed in this district in the evening, to aid in planning the next day's activities, and are based on conditions shown on the 8 p. m. charts.

Classification of storm types.—In attempting to group the 87 storms in relation to various types of pressure distribution (according to Humphreys' classification of thunderstorms (*2*)), four well-defined types of such distribution could be segregated.

Type I: Cyclonic, corresponding to Humphreys' "b" type (in the southeast or, less frequently, the southwest quadrant of a regularly formed LOW). Twenty-two of this type were noted. Contrary to the general rule, and for reasons to be stated later, in this region most of these occurred in the southwest quadrant of the LOW.

Type II: Anticyclonic, or trough storm, corresponding to Humphreys' type "d" (the region covered by a low-pressure trough between adjacent high-pressure areas). This type is most numerous, with 47 examples.

Type III: The border storm, corresponding to Humphreys' "e" type (along the boundary between warm and cold waves). This type was noted but once.

Type IV: This is a combination of Humphreys' classes "a" (regions of high temperature and widely extended nearly uniform pressure * * * local or "heat" storms) and "d" (defined under Type II), and is occasionally somewhat akin to "c" (barometric valley between the branches of a distorted or V-shaped isobar * * * the tornadic storm). It is marked by a somewhat variable distribution of pressure, but shows in all cases an area of relatively high pressure along the Pacific coast, or offshore, and an area of low pressure in the interior, wider than is the case under Type II, extending from the Cascade Mountains eastward, usually with a slight upward gradient toward the east, and marked by high temperature throughout. The area of high temperature and nearly uniform pressure may be extensive enough at times for the formation of heat thunderstorms, but the influence of the offshore HIGH, at least in Washington, is always to be seen during the life history of a Type IV storm. This type frequently develops from a storm of Type II. Among the 17 Type IV storms are the 2 which caused the greatest number of fires and the greatest damage in 1925 and 1926.

Data on the four types.—These are presented in the following tables:

TABLE 1.—*Annual distribution of storms*

Year	Type I	Type II	Type III	Type IV	Total
1924	0	14	0	7	21
1925	15	16	1	5	37
1926	7	17	0	5	29
Total	22	47	1	17	87

TABLE 2.—*Monthly distribution of storms*

Type	May	June	July	August	September	Total	Per cent of total
I	6	6	0	5	5	22	25
II	1	7	16	15	8	47	54
III	0	0	0	0	1	1	1
IV	0	0	7	6	4	17	20
Total	7	13	23	26	18	87	100
Per cent of total, by months	8	15	27	30	20	100	

TABLE 3.—*Geographical distribution of storms*

	Type				Total
	I	II	III	IV	
Western Washington	7	11	1	8	27
Eastern Washington	16	41	0	13	70
Total [1]	23	52	1	21	[1] 97

[1] The apparent discrepancy between the totals noted in Tables 2 and 3 is due to the fact that certain storms extended over both sections; hence a duplication in noting distribution.

TABLE 4.—*Storms resulting in fires, 1925 [1] and 1926 [1]*

	Type				Total
	I	II	III	IV	
In western Washington:					
All storms	4	7	1	2	14
Storms causing fires	2	5	1	1	9
Percentage of storms causing fires	50	71	100	50	65
In eastern Washington:					
All storms	18	26	0	8	52
Storms causing fires	1	13	0	3	17
Percentage of storms causing fires	6	50	0	38	33

[1] These years marked by more complete data on storms and fires.

TYPE CHARACTERISTICS

Type I (see fig. 1, pressure distribution at 8 p. m., August 31, 1925).—This, the cyclonic type, occurs most frequently in May, early June, late in August, and in September. (See Table 2.) During these months regularly formed LOWS, causing more or less general precipitation, rather frequently pass eastward over southern British Columbia or northern Washington. The lookout stations are not manned during the periods of greatest frequency (early and late in the season). Reports from the mountain districts during these periods would undoubtedly increase the number of recorded lightning storms attributable to this type of pressure distribution. Most of the lightning storms in western Washington accompany LOWS of this type which pass directly eastward from the North Pacific. Most of the LOWS affecting only eastern Washington are of the "Alberta" type, in which we find the lightning storms in the southwest quadrant, more commonly in August and September. When this type occurs there in normally a moderate temperature gradient between coast and inland stations, with relative humidity at or near the seasonal normal. Accompanying precipitation usually precludes any great danger from fires; in fact (see Table 4), but one fire in eastern Washington during the period of the survey has been chargeable to a storm of this type and but two of record in western Washington.

Type II (see fig. 2, pressure and temperature distribution at 8 p. m., July 10, 1926).—This, the "trough" or anticyclonic, is preeminently a summer or hot-weather type, and is responsible for 54 per cent of the storm days reported. Occurring most frequently in July and August, which are normally the periods of greatest fire hazard, with low humidity, light precipitation, and highly inflammable fire material, it is not strange that in 1925 and 1926 fires occurred with 70 per cent of the lightning storms of this type in western Washington and with 50 per cent of those in eastern Washington. The favorable pressure and temperature distributions are as follows: High pressure and comparatively low temperature along the coast and over the western section, with north-south isobars and isotherms, roughly parallel, and with low pressure and high temperature in the barometric valley, with a further gradient toward the east similar to but less steep than that toward the west. This situation presents, in effect, a "cold front" on the west and to a less degree on the east. Thus there is an overrunning of cool, moist air currents in connection with strong vertical convection and up-valley and up-mountain winds in the interior. This is a condition most favorable for extreme turbulence along the contacts of the conflicting air currents, and for the establishment of an adiabatic or superadiabatic gradient at or near the summits of the mountain ranges, from the Cascades eastward to include the Okanogan Highlands. Lightning storms result, scattered at times over large areas. The course of travel of each storm, its intensity, and the effectiveness of accompanying precipitation depend in each case on conditions at and close to their point of origin and on the immediately ensuing changes in the distribution of pressure and temperature.

Because the north-south isobars of lowest pressure in the trough seem frequently to be closed on the north and south (usually from lack of data that would call for their extension on the chart) this type frequently bears a surface resemblance to Type I. It can usually be distinguished, however, as being due to local conditions rather than to the eastward passage of a regularly formed LOW.

Type III. The border storm, or "cold-front" type.—This appears as a trough of low pressure, with its main axis in a general east-west direction, not north-south as in Type II. But one example has been noted during the three seasons of the survey—the storm of September 28, 1925. In this case the pressure gradients were not very steep, nor the temperature gradients remarkably so. Lightning was general in Washington west of the Cascades, and started many fires. Precipitation, while generally only of the order of 0.25 inch, was sufficient, with the high humidity, to prevent any great damage by the fires. The trough was the eastern extension of a secondary LOW of moderate intensity, moving southeastward in the path of a predecessor then central over Utah. The fact that the summer path of LOWS is normally somewhat farther north would seem to indicate that this type of storm should be comparatively infrequent and of little consequence except at the beginning and near the end of the fire season, when other conditions cause the fire hazard to be relatively low.

Type IV (see fig. 3, pressure and temperature distribution at 8 p. m., July 11, 1926).—This is a combination type, as has been stated. While it prevails there are frequently lightning storms that might be classified under the "heat" or "local" types in the region of high temperature and fairly even pressure farther east over Idaho and western Montana. In fact, such was the case on July 12, 1926, with widely spread storms and damaging fires in those States and in southeastern British Columbia. In Washington, however, the coastal high-pressure ridge is the normal seasonal condition. The onshore westerly winds induced thereby, adiabatically cooled in passing over the Cascades, may be regarded as the vehicles for the moisture necessary for the production of lightning storms on the eastern slopes of the mountains and over the hot, dry interior plateau.

DISTRIBUTION OF STORMS

While the various pressure types are generally quite obvious, two very important problems are to be considered in forecasting lightning storms for the forestry interests: First, the area to be affected must be delimited; second, the probability of effective precipitation must be indicated, and whether it will be fairly general over the area, or entirely local, confined to the space immediately under the storm clouds, and hence varying greatly in amount from place to place. A study of the exemplars

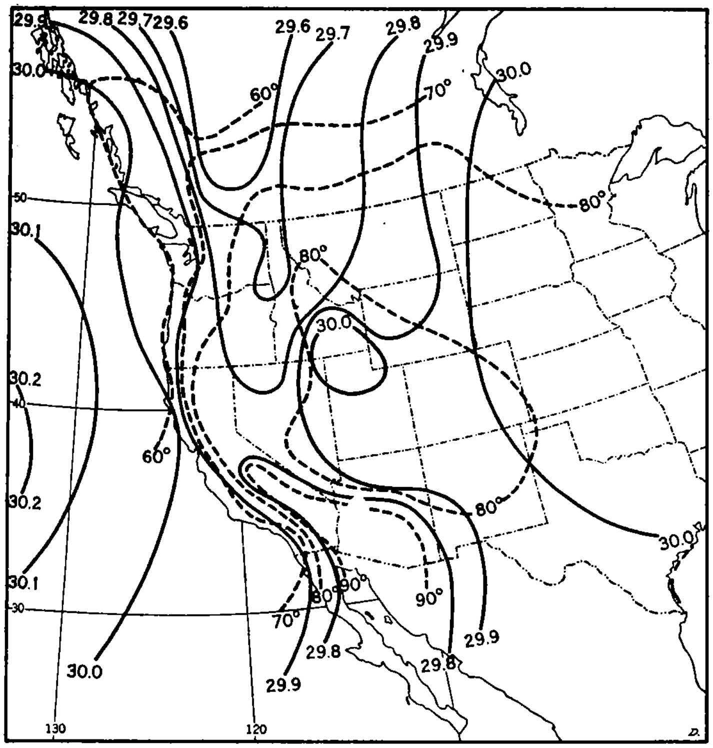

FIG. 1.—Distribution of pressure and temperature over the western United States at 8 p. m., August 31, 1925, resulting in lightning storms of Type I (cyclonic)

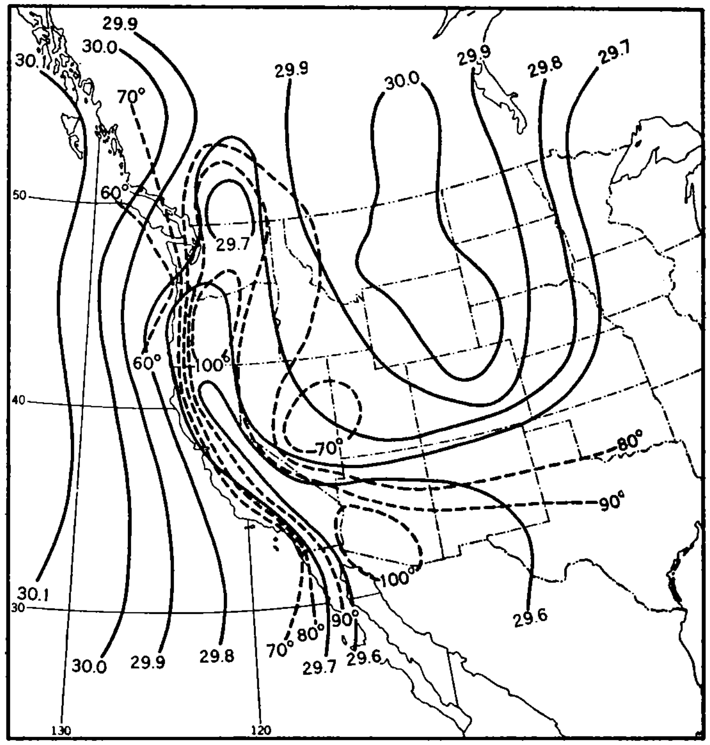

FIG. 2.—Distribution of pressure and temperature over the western United States at 8 p. m., July 10, 1926, resulting in lightning storms of Type II (anticyclonic)

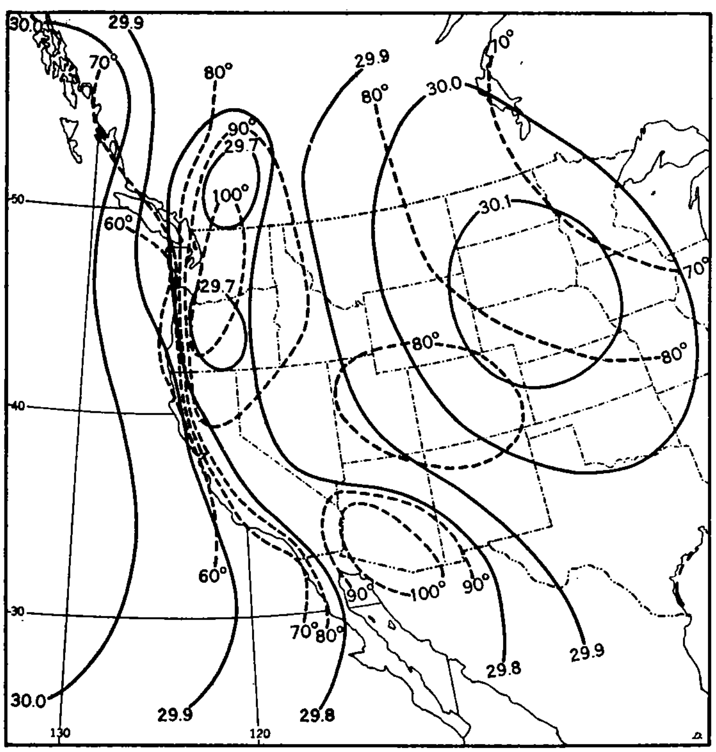

FIG. 3.—Distribution of pressure and temperature over the western United States at 8 p. m., July 11, 1926, resulting in lightning storms of Type IV (combination)

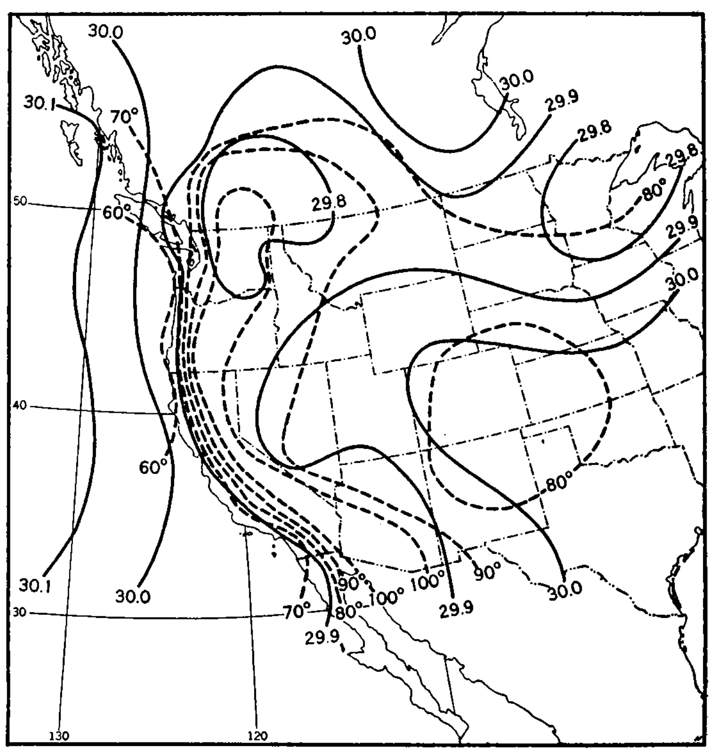

FIG. 4.—Distribution of pressure and temperature over the western United States at 8 p. m., July 12, 1926, resulting in lightning storms of Type IV

of Types II and IV, especially for the seasons of 1925 and 1926, allows one to draw certain tentative conclusions, which should be of value for the desired localization of the forecasts. As there is sometimes a certain similarity between Types I and II, and more frequently between II and IV, with a frequent development from the one to the other type, these conclusions apply in a measure to Type I, and more generally to Types II and IV.

In studying the possibilities of localizing the forecasts, the State of Washington may first be divided, by the line of summits of the Cascade Mountains, into two major climatic zones:

The western or maritime zone is further subdivided into, first, the Olympic Peninsula; second, southwestern Washington, with the Willapa Hills of the coast range; third, the western Cascade slopes, including (3a) the northern half, or the Mount Baker and Snoqualmie Forests and the contiguous lands westward to Puget Sound, and (3b) the southern half, or the western portions of the Rainier and Columbia Forests and contiguous area westward to the eastern boundary of section 2.

The eastern or continental zone is subdivided into (4a) the northeastern Cascades, including the Chelan and Wenatchee Forests and the Okanogan Valley; (4b) the southeastern Cascades, comprising the eastern portions of the Rainier and Columbia Forests and forested areas to the east; and (5) the Okanogan Highlands, including the Colville Forest, and generally all forest lands in the northeastern quarter of the State. There are not included in this study parts of the Kaniksu Forest in the northeast and the Umatilla Forest in the southeast, as these forests lie mainly in Idaho and Oregon, respectively; nor the unforested plateau of southeastern Washington.

Sections 1 and 2.—Reports of summer lightning storms are comparatively infrequent from sections 1 and 2; those of spring and fall storms of Types I and III are more frequent. Fires have been only infrequently caused by such storms and have rarely reached dangerous size, due to the generally favorable conditions of humidity and precipitation. Hence, for these districts, forecasts of lightning storms are, from the forester's standpoint, of minor importance. This is fortunate, as the development of storm-favoring conditions—i. e., the rate of approach of LOWS from offshore and their point of incidence on the coast, or the coming of a "cold front"—is frequently not well defined on the synoptic charts immediately preceding the actual arrival of the storms near the coast. From the sparse data at hand the principal means of recognizing the probability of lightning with such storms is the occurrence of temperatures (maxima particularly) somewhat above the seasonal normal at coast stations (Tatoosh Island, North Head, Marshfield, and at times Seattle and Portland) during the approach of a LOW. Abnormally high temperatures at the coast stations, with maxima in the upper eighties or nineties, as a rule are not indicative of lightning, being usually the effect of an inward movement of a HIGH on the north, with a general air circulation strong enough to prevent the local necessary convection, condensation, and turbulence in the upper air. In these two sections, then, moderately high temperatures with relative humidity normal or somewhat above are favorable for lightning storms; high temperatures with greatly subnormal relative humidity are unfavorable.

Sections 3a and 3b.—The western portion of these subdivisions—that is, the eastern Puget Sound Valley and the valleys of the upper Chehalis and lower Cowlitz Rivers—presents conditions comparable to those of sections 1 and 2. Type I storms are most frequent, and temperature and humidity are the best indices of storm probability, given favorable pressure gradients. Farther east the ranges and valleys of the western Cascades, by their irregularity of direction, tend to complicate matters. Temperatures are higher in the narrow valleys, convection and up-valley and up-mountain winds, with turbulence aloft, are more pronounced, and storms of Types II and IV are more frequent.

In the northern part of section 3a, portions of eastern Whatcom and Skagit Counties partake to a certain extent of the eastern régime of temperature, humidity, and precipitation, and especially with respect to storms of Types II and IV. This is due to the effects of certain transverse (north-south) minor ranges in shutting off the westerly winds from certain drainage basins and creating in effect, a western outpost of the eastern zone of pronounced convectional activity.

In the valleys of the Wind River and the White Salmon, tributaries of the Columbia River flowing southward through the southern Columbia Forest, a similar condition exists. The presence of the near-by Columbia Gorge, which is a channel for air as well as water, further complicates matters here. As easterly, down-valley, or westerly, up-valley, winds prevail in the gorge, the continental and maritime régimes alternate in the lower portions of the smaller tributary valleys. The lines of demarcation, meteorological and geographical, are neither constant nor sharply defined; hence localization of the forecasts within this section, either with regard to lightning or to changes in relative humidity, will always be rather difficult.

An examination of the synoptic charts just prior to storms in this southern Cascade region discloses one salient fact. Given similar types of pressure distribution the geographical distribution of lightning is governed by the march of high temperature and the extension of the low-pressure trough from west to east—that is, the areas of greatest convection and of greatest velocity of up-valley winds are the areas of greatest turbulence aloft, and are those in which the storms follow closely on the occurrence of abnormally high temperature.

This march of high temperature and the subsequent development and progress of storms, with enlargement of the storm area, is well illustrated by the synoptic charts (8 p. m.) for July 8 to 11, 1926. (See figs. 2 and 3.) At 8 p. m. on the 8th the North Pacific HIGH impinged on the coast of British Columbia and Washington, with highest pressure at Prince Rupert, and with a uniform gradient to the southeast, thus favoring northerly winds, high temperatures, and low humidity in the western portions of British Columbia, Washington, and Oregon. A trough of low pressure extended from the Mexican border northeastward, to include Minnesota. By the 9th the temperature in western Washington had arisen strongly, and by 8 p. m. the part of the HIGH which had extended inland was practically bisected by a heat-induced trough of low pressure, extending northward to Kamloops, British Columbia, from the semipermanent Arizona-California LOW, with lowest pressure and highest temperature in western Washington. On this date abnormally high temperatures were reported from the southern Cascades, and on the 10th lightning occurred in the vicinity of the reporting stations.

Conditions remained similar on the 10th (see fig. 2)—that is, high pressure along the coast, and with the trough central at Kamloops and Portland. The temperature continued to rise in the interior of the west portion of the two States (the absolute highest of record being reported from Portland and Roseburg on this date). There remained an area of moderately high pressure, with a lesser gradient toward the west, over the northern plateau, with its center moving eastward. On the 11th lightning storms continued over the southern Cascades and appeared on the eastern slopes, central and southern, over those areas marked by rising temperature on the 10th. (This persistence of extremely high temperature in the interior of western Washington and Oregon is rather an unusual phenomenon.)

By 8 p. m. of the 11th (see fig. 3) the low-pressure trough had extended eastward, covering the northern Rocky Mountain States, with rising temperatures in eastern Washington (where highest temperatures of record were noted on this day), Idaho, Montana, and southeastern British Columbia. The North Pacific HIGH remained stationary, causing westerly winds in western Washington and beyond the summits of the Cascades, as indicated by reports from lookout stations. The lightning-storm area of the 12th was practically coextensive with the area of rising temperature on the 11th, and no further storms were reported from the region of westerly winds and lower temperature in the west.

By 8 p. m. of the 12th a readjustment of offshore pressure was indicated. A LOW of moderate intensity was passing eastward over southern British Columbia and joining with the trough, while pressure along the coast of Oregon had greatly increased. This combination caused southwest winds over eastern Washington, at the surface and aloft, strong enough to overcome the previous convectional activity, and no lightning was reported in Washington after 11 p. m. on that date. It is believed that the storms continued during the early morning of the 13th in Idaho and British Columbia; exact data are not available, however.

The march of the storm area is indicated on Figure 5, by isobronts of the average hour on which lightning was first reported at the various stations on July 10, 11, and 12. On the 12th there appear to have been two well-defined groups of storms, one beginning at noon, the other at 2 p. m. (one hundred and twentieth meridian time). The failure of the isobronts of the 11th and 12th to extend to the southeast is due to lack of detailed reports from that part of the State; the storm of the 12th did extend over that section, as indicated by reports from several cooperative observers, who, however, did not state the hours of beginning and ending. It should be remarked that in the southern Cascade section high temperatures occurred on the 9th and 10th; lightning began on the 10th and continued on the 11th. In the central portion of the eastern Cascades, similarly, with high temperatures on the 10th and 11th, there was lightning on the 11th and 12th. This is a somewhat unusual case of persistence.

In this connection it may be said that while the wind at Spokane is from the southwest very few lightning storms of Types II and IV are noted in eastern Washington and none at all when such winds are of 10 miles per hour or more, and are obviously winds under the influence of the general gradient rather than purely local in character. This is not so in the case of the cyclonic Type I, in which most of the storms are in the southwest quadrant, and southwesterly winds are quite frequent.

While the typical storms just discussed are distinctive and the correlation between cause and effect quite obvious, the situations are usually rather more complex; hence extensive generalization seems unsafe. A study of the synoptic charts for the three summers shows, in fact, frequent recurrences of what appear to be very good lightning-storm types, following which no lightning has been reported. In such cases, however, it is uncertain whether actually no lightning occurred or whether it was simply not seen or reported. It is reasonable to believe that the latter has often happened.

PRESSURE AND TEMPERATURE DISTRIBUTION

While characteristic pressure and temperature distributions are illustrated on the type charts, the consistency of these distributions is better shown by tabulating for selected stations the average 8 p. m. pressure and temperature preceeding storm days. The stations chosen show, as well as so small a number can, the pressure

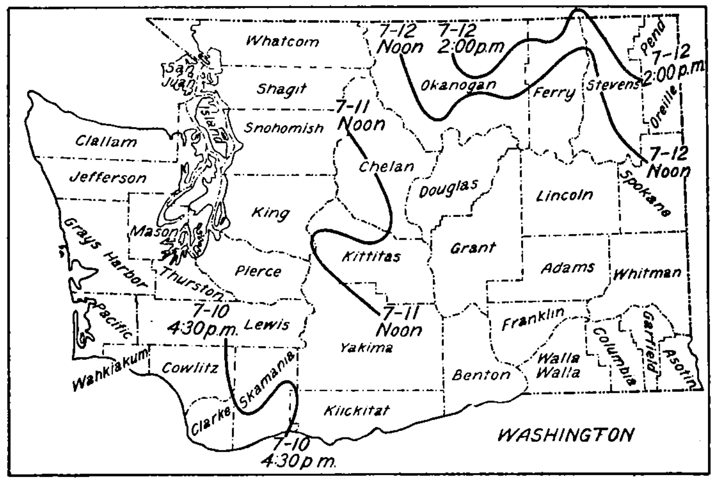

FIG. 5.—Isobronts: Average hour of beginning of lightning in series of storms of July 10, 11, and 12, 1926

gradients and differences in temperature which are effective in causing local "cold fronts," which result in lightning storms.

While it may not be entirely safe to compute averages for so short a period, the number of examples of each type and the similarity of the averages and differences for each season to those of the entire period make the figures in Tables 5 and 6 interesting, and give them a certain corroborative value in the attempt to fix type characteristics.

TABLE 5.—*Average pressure and temperature at 8 p. m., preceding lightning-storm days*

Storm type	Pressure				Temperature			
	Tatoosh Island	North Head	Yakima	Spokane	Seattle	Portland	Yakima	Spokane
	Inches	*Inches*	*Inches*	*Inches*	°	°	°	°
I	29.924	29.967	29.853	29.822	64.6	67.6	71.7	72.4
II	30.006	30.022	29.811	29.854	71.8	78.1	87.6	84.8
IV	30.025	30.039	29.833	29.857	71.3	76.8	83.6	82.5
Average	30.003	30.021	29.825	29.848	70.1	75.5	83.2	81.8

NOTE.—The average is computed from the total number of dates, not as an average of type averages. Type III is omitted from the tabulations.

TABLE 6.—*Average pressure and temperature gradients at 8 p. m., preceding lightning-storm days*

Storm type	Pressure differences				Temperature differences			
	North Head-Tatoosh	Yakima-Tatoosh	Spokane-Tatoosh	Spokane-Yakima	Portland-Seattle	Yakima-Seattle	Spokane-Seattle	Spokane-Yakima
	Inch	*Inch*	*Inch*	*Inch*	°	°	°	°
I	0.043	−0.071	−0.102	−0.031	3.0	7.1	7.8	0.7
II	.016	−.195	−.152	.043	6.3	15.8	13.0	−2.8
IV	.014	−.192	−.168	.024	5.5	12.5	11.2	−1.3
Average	.018	−.178	−.155	.023	5.4	13.1	11.7	−1.4

LIGHTNING STORMS AND FIRES

While the occurrence of lightning storms and the possibilities of accurately forecasting them are of prime interest to the meteorologist, to the forester such storms are interesting mainly because they cause fires. Since not every storm starts a fire, even though widespread and marked by intense electrical display, the number of lightning fires and the extent of the damage must be affected by weather conditions which precede and follow the actual lightning flashes.

In a very exhaustive analysis of the lightning reports from the lookout stations in Forest District No. 1 (northern Rocky Mountain region) for the years 1924 and 1925, Mr. H. T. Gisborne (*3*) has suggested that the difference in the number of lightning fires during these years may be explained by the difference in average duration of rainfall before and after the first and last flashes of each storm were observed, and by a small difference in the averages of the reported percentage of flashes confined to the clouds.

The lightning reports for the three seasons in Washington are made on the same form, contain the same classes of information, and are presumably about as accurate as those in District No. 1. A scrutiny of the percentage of flashes reported as having been confined to the clouds and of the total number of flashes in each storm (the latter not always stated) indicates that such a comparison of percentages as between "safe" (nonfire-causing) and "dangerous" (fire-causing) storms can not at present be given much weight as determinants of the safety factor. This conclusion is based on the following items:

(*a*) Probability of error in determining the number and striking point of flashes.

(*b*) Probability of error in computing percentages. This is because the number of cloud-to-cloud flashes and of cloud-to-earth flashes are not specified, nor even the total number of flashes in many cases. One observer reported for a certain storm a total of one flash, with 75 per cent of flashes from cloud to cloud.

The percentages are interesting, and they would, if the data were unimpeachable, be important.

There is a similar lack of authority in the reports as to the duration of precipitation before and after the flashes. The lookouts report this in minutes (duration of period between flashes having to be interpolated) and the amounts of precipitation, as light, moderate, or heavy, with occasional qualifying adjectives. In but few cases are instrumental measurements given. During certain storms the amounts reported vary from none, through light, to extra heavy (for the same storm and within a circumscribed area), which is quite natural and to be expected. At times those stations reporting heavy precipitation report numerous fires, while those reporting no rain or little, report few or no fires; occasionally the reverse is true. This, due to the purely local character of most of the summer storms of Types II and IV, is also natural and to be expected. Also, one must consider the fact that bolts from local lightning storms not infrequently strike at points somewhat distant from the region immediately beneath the storm cloud (*4*), which would receive the greatest amount of precipitation. Hence the quantity or duration of precipitation reported by individual observers for any fixed points is not a valid index to use in classifying the storms as "safe" or "dangerous."

In addition to the precipitation reported by the lookouts I have considered the precipitation reported by regular cooperative observers. To correlate numerically the precipitation amounts with the number of fires resulting from any given storm has not been practicable, but there has been noted a fairly close relation between the number of fires and the extensiveness of the rainfall. In cases where precipitation has occurred at only a few very scattered stations, even with amounts ranging from a trace to 0.90 or 1 inch (the lookouts reporting from "very light" to "extra heavy"), numerous fires have been reported. Types II and IV are characterized by this variable, localized precipitation, and for eastern Washington are preeminently the dangerous storms. Again, with precipitation rather light, 0.01 to 0.30 inch in varying amounts, but *general*, thereby increasing the probability of effective amounts precisely at the location of the lightning strikes, few fires, and generally none, have been reported. Such as are reported are usually easily extinguished, being for the most part class A fires (one-fourth acre or less). This general spread of precipitation is characteristic of the cyclonic Type I and partly explains its comparative innocuousness.

In western Washington reports of storms of Types II and IV are fewer but the percentage of dangerous storms of these classes is greater than in the eastern section. This is partly because over a rather large area the chief source of information about the occurrence of storms has been the reports of fires caused by them, and probably partly because the more abundant fire material is at its seasonal peak of inflammability during the lightning season. Precipitation in this section during the known dangerous storms has been light and scattered, except in the one notable example of Type III.

Relative humidity and temperature before and just after storms probably affect their fire-causing character more than do attendant conditions. An examination of conditions prior to and subsequent to the storms that have resulted in the most widely destructive fires discloses two significant features—high temperature and low relative humidity prevail before and after the storms, and changes in these elements during the storm are of but brief duration. The effect is threefold: Forest materials have become highly inflammable just prior to the storm, the amount of effective precipitation is lessened by partial evaporation of the rain as it falls (complete evaporation before reaching the ground has been frequently noted in arid regions under similar circumstances), and rain that does reach the earth is evaporated very rapidly, the régime of high hazard being quickly reestablished.

Pressure distribution and temperature at 8 p. m. just preceding dangerous storms are shown in Tables 7 and 8 and the relative humidity for the same observation in Table 9 following:

TABLE 7.—*Average pressure and temperature distribution at 8 p. m., preceding "dangerous storms"*

	Pressure				Temperature			
	Tatoosh Island	North Head	Yakima	Spokane	Seattle	Portland	Yakima	Spokane
Western Washington, dangerous storms	29.903	29.893	29.786	29.820	77.2	83.3	88.0	84.7
Eastern Washington, dangerous storms	29.981	30.019	29.773	29.803	75.0	80.3	92.6	90.3
Eastern and western Washington, all storms	30.003	30.021	29.825	29.848	70.1	75.5	83.2	81.8

TABLE 8.—*Average pressure and temperature gradients at 8 p. m., preceding "dangerous storms"*

	Pressure difference				Temperature difference			
	North Head-Tatoosh	Yakima-Tatoosh	Spokane-Tatoosh	Spokane-Yakima	Portland-Seattle	Yakima-Seattle	Spokane-Seattle	Spokane-Yakima
Western Washington, dangerous storms	−0.010	−0.117	−0.083	0.034	6.1	10.8	7.5	−3.3
Eastern Washington, dangerous storms	.038	−.208	−.178	.030	5.3	17.6	15.6	−2.3
Eastern and western Washington, all storms	.018	−.178	−.155	.023	5.4	13.1	11.7	−1.4

TABLE 9.—*Average per cent of relative humidity at 8 p. m., preceding "dangerous storms"*

	Seattle	Portland	Wind River Experiment Station	Darrington	Spokane	Republic	Leavenworth
Western Washington, dangerous storms	44.6	44.0	42.0	45.0	-------	-------	-------
Eastern Washington, dangerous storms	46.9	46.1	-------	-------	19.2	23.8	23.5
Eastern and western Washington, all storms	52.0	48.8	44.0	50.0	25.1	27.6	29.3

As pointed out previously, pressure and temperature distribution govern the location of the storms. From the three tables above it will be seen that the degree of accentuation of a given type of pressure and temperature seems to govern the degree of danger from the individual storm. Except that lightning fires are often harder to suppress than others, because they often occur in inaccessible locations, they are, once started, no different from those originating from any other source. They react in like manner to changes in the "fire-weather" conditions. During the period 1916–1926, for which specific figures for the national forests are available, every period marked by great damage from lightning fires in the Washington forests (the acreage burned over being the index of damage) has been preceded by generally subnormal precipitation and relative humidity, and the fires were neither controlled nor suppressed until these subnormal conditions were relieved.

Forestry interests have suggested that forecasts of lightning storms include some indication as to the expected "safe" or "dangerous" character of the storm. Having in mind the fact that the degree of danger to be expected varies inversely with the amount and extensiveness of the accompanying precipitation and with changes in the fire hazard, we may ordinarily consider that storms of Type I (usually occurring during periods of nearly normal humidity and attended by general rainfall) are "safe"—that is, few, if any, fires are to be expected. But the very nature of Types II and IV, typical summer storms, with scattered, light precipitation and subnormal humidity, would usually preclude the possibility of such a predesignation, except under extraordinary circumstances.

It may not be feasible to forecast "safe" storms in July and August, but, on the other hand, it may at times be entirely proper to include in the forecast, when a storm is seen to impend during a period of generally high fire hazard but without probability of ameliorating the conditions, a statement that general conditions favor the establishment of fires. While general verification of such a forecast might not be expected over any large area, the information might be of value in regulating the activities of suppressive forces in zones known to be particularly subject to storms and to lightning fires.

The ignition of forest material by lightning would seem to be somewhat fortuitous, depending on whether the strikes are on inflammable material, as growing trees, snags (tall dead trees or stumps), duff, or moss, or on the bare mineral earth or grassy meadows. There is dearth of authenic information as to the material in which most fires start. Strikes are frequent on green trees and tall snags, as may be seen from their splintered condition. Whether fires in such cases are caused by blazing splinters, ignited moss, or in the duff ignited during the grounding of the bolt is difficult to determine, as in most cases the evidence is consumed before examination is possible. There seem to be certain well-defined storm paths, and in these paths certain areas are marked by many fires. While topography would influence the conditions that cause storms, and hence the storm paths, the reasons for differing susceptibility to fires will have to be determined by investigation in each district.

CONCLUSIONS

1. Lightning storms are of outstanding importance among the meteorological phenomena affecting the fire hazard in Washington, and in the Pacific Coast States in general. Localization of forecasts of such storms is highly desirable.
2. Such storms in Washington, with reference to the pressure distribution causing them, are classified under four types—I, the cyclonic; II, the trough, or anticyclonic; III, the border storm; IV, a combination of the trough and the local or heat storm.
3. Storms of Type I are least dangerous, from the standpoint of resultant fires and damage, while those of Type III are infrequent. Fires are very probable after storms of Types II and IV. High pressure along the coast and high temperatures in the interior, with pronounced gradients, are the dominating features attending the dangerous types.
4. The local occurrence of lightning storms is governed by orographic and climatic conditions, the storms being most frequent in zones of highest summer temperature, with marked convectional activity and up-mountain winds. Given suitable pressure distribution, individual storms follow the march of high temperature from west to east at an interval of 12 to 36 hours after the temperature maxima. This should allow us to localize the forecasts.
5. The occurrence of fires after storms seems to be limited by the degree of distribution and the amount of accompanying precipitation, rather than by its purely local intensity. The extent of damage from such fires is governed by the seasonal degree of inflammability of the fire material and by the occurrence of fire weather before and after the fires are established.

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